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RESEARCH DEPARTMENT



REPORT

**SATELLITE BROADCASTING:
spectrum efficiency of
television services in the 12GHz band**

No. 1970/38

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G.J. Phillips, M.A., Ph.D., B.Sc., M.I.E.E.

D. Maurice
Head of Research Department

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SATELLITE BROADCASTING: SPECTRUM EFFICIENCY OF TELEVISION SERVICES IN THE 12 GHz BAND

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SATELLITE BROADCASTING: SPECTRUM EFFICIENCY OF TELEVISION SERVICES IN THE 12 GHz BAND

Summary

The report is confined to a study of the use of geostationary satellites transmitting in the 12 GHz band to provide multiple television broadcast services within a wide area. The theoretical possibilities are first examined with reference to an ideal lattice of just-overlapping circular service areas. By proper assignment of satellite positions in the equatorial orbit and of frequency channels, using wideband f.m., it appears that many services in an area such as Europe may share the same channel. The directivity of both transmitting and receiving aerials is important in achieving the necessary protection against mutual interference. Exploratory assignments for Europe (and some adjoining areas) suggest that one national programme could be provided to almost every country using a frequency range of about 120 MHz.

1. Introduction

Long-term developments in television broadcasting are likely to include some form of broadcasting from geostationary satellites, using the 12 GHz frequency band. One aspect that requires careful study is the way in which services to many areas or countries might be provided without mutual interference, and with reasonable economy in the total frequency band used. This report studies fundamental limitations, as indicated by considering service areas in the form of an ideal lattice, and also examines the provision of national services within the European Broadcasting Area, respecting actual national boundaries. Similar work has been reported,¹ primarily for a broadcasting system for community reception, but it is intended here to show in a more definite way how the spectrum requirements depend on the extent to which the satellite is placed east or west of the position that would be ideal if interference protection were disregarded.

2. Basic system requirements and constraints

2.1. Directivity of transmitting and receiving aerials

Requirements for services in an area such as Europe will probably include purely national services and satellite transmitting aerials could have the necessary directivity in the 12 GHz band to confine most of the power to areas a few hundred kilometres in breadth. We shall therefore consider service areas covered by satellite transmissions with a beamwidth of the general order of one degree, but it will be seen that the conclusions are not critically dependent on the transmitter beamwidth. A beam of circular cross-section with one degree total width will cover an area which is about 650 km across in the east-west direction, and extends over a greater distance in the north-south direction depending on the latitude of the target area.

System calculations have usually assumed that the maximum dimension of a domestic receiving aerial should not exceed 1 metre. For convenience we will assume in this report that the receiving aerial uses a paraboloid reflector of 0.9 metres diameter, giving a 2° receiving beamwidth (-3 dB points) at 12 GHz.

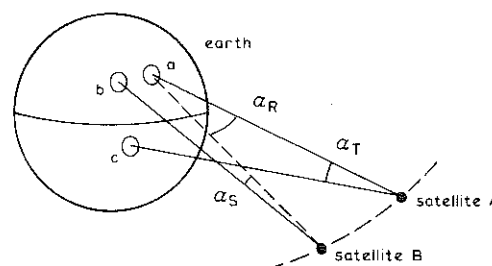


Fig. 1 - Geometry of paths

The provision of as many services as possible on the same frequency channel must exploit the directivity of the transmitting and receiving aerials as illustrated in Fig. 1. If satellite A is providing a service to area *a*, the interfering signal from a co-channel service from satellite B to area *b* can be controlled by the combined effect of the off-axis reception (angle α_R), and off-axis transmission (angle α_S). Provided that the transmitting aerial discrimination is high enough to provide the co-channel protection ratio required, there will be some area *c* sufficiently far from *a* that may be served from the same satellite* A, relying entirely on the protection provided by the off-axis transmission (angle α_T). In the general case the two aerial discriminations

* From the planning point of view it is immaterial whether transmissions which are permitted from the same orbital position are actually made from the same satellite or from separate satellites which are kept close to the same nominal orbital position.

provide more effective mutual protection of co-channel services than could be achieved by one aerial, but it will be appreciated that planning to take full advantage of this will require careful assignment of satellite positions as well as frequency channels for the various services. Although interference would be unlikely in the early stages of satellite broadcasting, failure to conform to an agreed system of allocation could mean that the future use of satellites by various countries to the fullest possible extent might be prejudiced.

2.2. Assumed aerial directivities

In calculations of the contribution of transmitting or receiving aerial directivity to the protection against an interfering signal, the following formula will be used for the reduction R in gain at an off-axis angle ϕ for an aerial with a total beamwidth of ϕ_0 at the -3 dB points:

$$R = 10.5 + 25 \log_{10} (\phi/\phi_0) \text{ dB} \quad (1)$$

This applies for values of $\phi \geq 0.5\phi_0$ with the proviso that for the larger values of ϕ , R should not be assumed to exceed the gain of the aerial, in dB, over an isotropic aerial. This formula is based on the rate of change of gain with off-axis angle proposed by the CCIR for highly directive microwave aerials used in satellite communication systems (CCIR Report 391, Oslo, 1966), but is adjusted to correspond to aerials of only moderate performance in regard to smallness of sidelobes.

2.3. Modulation system, channel width and protection ratio required

In preliminary studies of television broadcast satellite systems (for example those in CCIR Report 215-2, New Delhi, 1970) it is clear that the adoption of vestigial-sideband a.m. as in conventional television broadcasting would require impractically high powers for the satellite transmitters. Frequency modulation systems, however, offer a substantial saving of power at the expense of greater channel-width.

It turns out from preliminary calculations that frequency modulation is also preferable to a.m. on the grounds of efficient spectrum usage. The fact that a smaller co-channel protection ratio is required, i.e. that f.m. transmissions can tolerate a lower ratio of wanted-to-interfering signal levels without being visibly affected, leads to the possibility of several services within an area of the size of Europe operating on the same frequency channel. This more than compensates for the fact that f.m. requires a wider channel than does vestigial-sideband a.m. Emphasis will therefore be given to f.m. systems but the frequency deviation may be varied in order to see how this affects the overall spectrum efficiency.

It should perhaps be added that f.m. is taken merely as an example of a system that exchanges bandwidth for immunity to noise and interference over a range of values that is useful for television broadcasting; the discussion is not intended to rule out some other system (based on digital coding with carrier phase-shift modulation for example) that might offer a similar exchange but might be more attractive for other reasons.

Table 1 below suggests necessary protection ratios for various f.m. systems as preliminary estimates made from the limited data available. Experiments are in hand to determine the protection ratio required for a 625-line f.m. signal which includes PAL colour and a suitable subcarrier channel for sound. The ratios given are the ratio of wanted to interfering f.m. carrier levels for just perceptible interference.

TABLE 1

Parameters and provisional co-channel protection ratios for f.m. television, 625-lines

Peak-to-peak deviation MHz	Approximate channel width MHz	Protection ratio required dB
8	20	30
12	24	26
16	28	23
20	32	21
28	40	18

3. Idealised arrangement of service areas

3.1. Basic assumptions

We consider service areas consisting of just-overlapping circles in a hexagonal lattice. Strictly this is possible only on a flat surface; for the spherical Earth some distortion would be necessary from a near-perfect arrangement at low latitudes to some modified form at high latitudes, but this will be ignored for the present. Service areas will be assumed to be defined by transmitting beams with a circular cross-section and 1° beamwidth. The only interference protection considered will be that between co-channel transmissions; adjacent-channel or image-channel interference will be assumed to have been rendered negligible by the use of suitable receivers and channel spacing.

Fig. 2(a) illustrates a typical example of an idealised lattice in which the use of three frequency channels and nine satellite positions is envisaged. Each area is labelled with the number of the channel and a letter denoting the orbital position of the satellite providing the service. Examination of various possibilities shows that the most efficient systems are those in which the number of channels S is one of the series of numbers $(p^2 + q^2 + pq)$ where p and q are zero or positive integers, as in the case of terrestrial transmitter networks.^{1,2,3} In such a lattice it may be shown from geometrical considerations² that if S is the total number of channels employed to cover a large area, the same channel must be re-used in a regular lattice of areas the closest of which have a centre-to-centre spacing d_S equal to $r\sqrt{3S}$, where r is the radius of each area. For 1° beams this spacing may be expressed as $0.5\sqrt{3S}$, measured as the angle subtended at a point in the geostationary satellite orbit. The thick-line circles show areas

using channel 1 for an example in which $S = 3$. If co-channel areas at spacing d_T have sufficient separation to permit re-use of the same satellite (e.g. areas a and c in Fig. 1) it may be shown that $d_T/d_S = \sqrt{T}$ where T is the number of satellites, suitably spaced in orbit, that are required to provide all services without co-channel interference. Thus, in addition to the concept of a lattice of channel assignments with repetition distance d_S (as is familiar in terrestrial broadcasting) we have a grouping in a super-lattice of satellite-position assignments with a repetition distance d_T . In the example of Fig. 2(a) the value of T is 9, and the nine orbital positions A to I are shown in Fig. 2(b). T , like S , must be of the form $(p^2 + q^2 + pq)$, with p and q zero or positive integers, if the letter assignments are to form a regular lattice in the same way as the channel numbers.

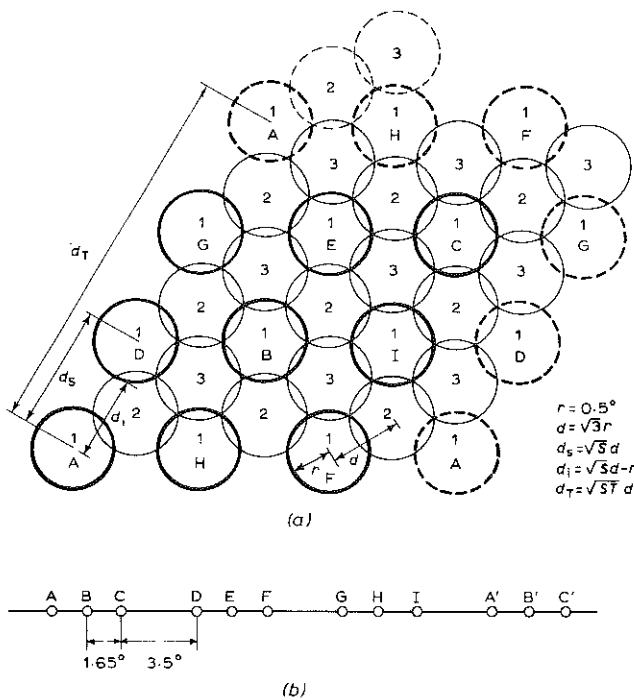


Fig. 2 — Example of satellite positioning and area assignment

(a) Idealised lattice for broadcast service areas (beamwidth 1° , $S = 3$, $T = 9$)

(b) Arrangement of satellites in orbit for $T = 9$

3.2. Examples of systems

Starting with an assumed channel width and an assumed number of channels (and hence a determined total bandwidth) we can derive an example of an ideal lattice system. Some examples are shown in Table 2, in which, at the top, the assumed values are shown under items 1 and 2. The total aerial discrimination required to act on the interfering signal is given as item 3; this is based on the protection ratio (Table 1) with 6 dB added; this includes an allowance of 3 dB because, at the limit of service, the wanted signal falls 3 dB below the maximum signal strength on the beam axis, and a further 3 dB allowance for multiple interference effects. Next, the transmitting aerial dis-

crimination is determined for the closest areas using the same channel. Thus the angle subtended at the satellite between the edge of the zone of the wanted service and the axis of the interfering transmitter beam (d_i in Fig. 2) gives the appropriate value of ϕ for determining the discrimination from Equation 1. The geometry of Fig. 2 gives $\phi = 0.5(\sqrt{3S} - 1)$ degrees; also $\phi_0 = 1^\circ$ corresponding to the beamwidth of the satellite transmissions. The deduced transmitting aerial discrimination is given as item 4(i), while item 5(i) is the receiving aerial discrimination required, derived by subtraction of the first figure from the total in item 3. Corresponding calculations have also been made for the next closest co-channel areas under (ii) and (iii), for reasons explained later. The spacing of satellites that subtend a sufficiently large angle for the receiving aerial to give the required discrimination is given in item 6. The angles are deduced by applying Equation 1, ϕ being determined for the required value of R with $\phi_0 = 2^\circ$ corresponding to the receiving aerial beamwidth.

We have now to assign a satellite position (denoted by a capital letter) to each co-channel area. This is done in the example of Fig. 2 for the channel 1 areas. A unit of the lattice is determined by the spacing of areas (d_T) for which the transmitting aerial alone just provides the required discrimination. Such a unit will contain T co-channel areas, and when a corresponding number, T , of spaced satellites has been employed, the same satellites may be re-used. We thus have the concept of T satellites being sufficient for an indefinitely large lattice of service areas. Where $T \leq 7$, the satellites are regularly spaced at the angle determined in 6(i), so as to provide the necessary protection between adjacent areas. Where $T > 7$ it is possible to determine sequences of the satellites such that the average spacing may be reduced. Thus two satellites may be spaced closer together provided that the areas they serve do not have the closest spacing. The permitted satellite spacing must then be deduced from the additional cases calculated under (ii) and (iii) in Table 2. Geometrical configurations of the lattice and the satellite sequences are given for certain cases of interest in Fig. 3.

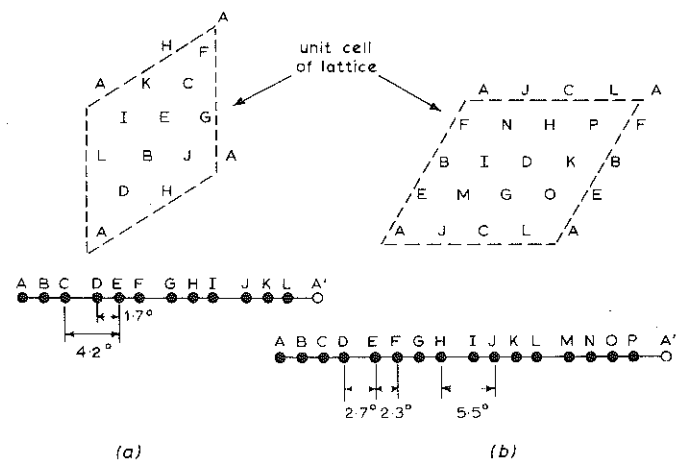


Fig. 3 — Further examples of satellite positioning and area assignment

(a) $T = 12$ (b) $T = 16$ (Spacings are given for $S = 3$)

TABLE 2

Examples of idealised systems

1. Assumed channel width, MHz	20	24			28			32
2. Number of channels assumed (S)	9	7	4	3	7	4	3	3
3. Total aerial discrimination* required, dB	36	32	32	32	29	29	29	27
4. Contribution of transmitting aerial, dB								
(i) for closest areas	18.5	16.7	12.7	10.5	16.7	12.7	10.5	10.5
(ii) for next closest	25.5	24.3	20.3	18.5	—	20.3	18.5	18.5
(iii) areas (if needed)	27.4	—	22.2	20.3	—	—	20.3	—
5. Contribution of receiving aerial needed, dB								
(i)	17.5	15.3	19.3	21.5	12.3	16.3	18.5	16.5
(ii)	10.5	7.7	11.7	13.5	—	8.7	10.5	8.5
(iii)	8.6	—	9.8	11.7	—	—	8.7	—
6. Minimum satellite spacings to give item 5								
(i)	3.9°	3.2°	4.6°	5.5°	2.5°	3.4°	4.2°	3.5°
(ii)	2.0°	1.5°	2.3°	2.7°	—	1.7°	2.0°	1.65°
(iii)	1.7°	—	1.9°	2.3°	—	—	1.7°	—
7. Total number of satellite positions** (T)	12 (33.7)	9 (30.5)	12 (29)	16 (29)	4 (26)	9 (27.4)	12 (27.4)	9 (25.5)
8. Frequency range per programme choice, MHz	180	168	96	72	196	112	84	96
9. Maximum longitude offset of satellite	11.2°	9.3°	13.0°	19.7°	5.0°	10.2°	11.8°	10.2°

* This equals the required protection ratio plus a 3 dB allowance for the fall-off of the wanted signal at the service limit and a further 3 dB allowance for multiple interference.

** Figure in brackets gives the protection, in dB, provided by the transmitting aerial for co-channel areas served from the same satellite position. The product ST has been chosen to give approximately the required protection ratio plus 3 dB, (no multiple interference allowance).

Under item 7 in Table 2 the value of T chosen for the examples is somewhat arbitrary because the actual discrimination (given in brackets) is in the range 3 to 4.5 dB more than the protection ratio, i.e. a full allowance for multiple interference is not included. It was felt that, as protection is entirely a function of transmitting aerial properties, some improved performance could compensate; also the number of co-channel signals of this type would be very small.

The important aspect of the finite number of T satellites is the total arc they occupy. The preferred satellite position is slightly west of its target area, say about 10°W in longitude, to avoid eclipse of solar power before local midnight. The sequence of T satellite

positions may be repeated round the geostationary orbit; thus for the particular letter assignment of a given service area there is a choice between satellite positions separated by an angle equal to the total occupied arc. The difference between the best satellite position available and the ideal position need never exceed half the arc, i.e. $\frac{1}{2}(AA')$ where AA' (as indicated in Figs. 2 and 3) is the arc occupied by one sequence of satellites. Item 9 of Table 2 indicates this maximum offset, while item 8 gives the total bandwidth as determined by the number of channels multiplied by the channel width. This bandwidth would provide each area with its own service. For each additional programme a similar bandwidth would be required; we may thus call it the frequency range per programme choice.

3.3. Discussion of results

The results given in Table 2 show certain interesting trends. First of all the total frequency range per programme choice (item 8) is of the order of 100 MHz, with an indication that 24 or 28 MHz channel widths lead to the least demand on total frequency range. However, the smallest frequency range achieved is at the expense of a greater offset of the longitude of the satellite (item 9), viz. nearly 20° instead of the order of 10° achieved by the other examples. Finally there is an indication that 3 or 4 channels only need be used to obtain efficient arrangements from the point of view of spectrum efficiency. The indications of Table 2 regarding the optimum channel width and number of channels probably give a good guide to the kind of system that should be explored, while the absolute figures of bandwidth requirements must be treated with some reserve because the calculations are based on an ideal lattice system.

3.4. Effect of service area size and receiving aerial directivity

The above examples assumed for simplicity that the service areas in the lattice correspond to a satellite transmitting beamwidth of 1° . If this beamwidth and hence the service areas were modified in size (while still of the general order of 1°) the lattice network would be changed only in scale not in form, and the conclusion would not be affected.

On the other hand, if the gain and hence beamwidth of the receiving aerial were changed, the service area lattice would be unaffected, but the spacings of the satellites would have to be modified. For example, if the receiving aerial beamwidth were 4° instead of 2° , the satellites would have to be doubled in their separation from one another to permit the same degree of protection by the receiving aerial to be achieved. At the same time the departure of the satellite longitude from the ideal would also be doubled. This would apply, for example, if lower frequencies than 12 GHz are considered since an aerial of reasonable size, e.g. 0.9 m diameter, has a wider beamwidth at lower frequencies, the beamwidth being inversely proportional to frequency.

3.5. High-latitude obliquity effects

The main effect of obliquity of the angle of arrival of the satellite signal is to elongate in a north-south direction the shape of the coverage area from a circular transmitting beam.⁴ There would, however, be no difficulty in transmitting an elliptical beam that largely compensates for this. There remains the difficulty that circular areas of fixed size do not pack uniformly on a curved surface as they do on a flat surface. The idealised lattice would therefore have to be distorted in some way from a near perfect arrangement at low latitudes to some modified system at higher latitudes. One method would be to decrease the east-west dimensions of the service areas gradually with increasing latitude so that they always corresponded to a fixed interval of longitude. This question is, however, rather academic in view of the more detailed work that is described in Section 4; the lattice study was intended only to give a broad indication of the possibilities.

4. Heuristic assignments of channels and satellite positions for national services in the European area

For the purpose of showing assignment possibilities, a list of 39 countries in the European Broadcasting Area (including N. Africa and the Near East) was drawn up in approximate order of decreasing population. The territories within the USSR were not included in the trial as their treatment as a single country served by one satellite transmission would lead to difficulties. Splitting up into areas comparable in size with other countries would avoid difficulty, but this was not attempted as the number of separate countries was already large enough to permit a realistic exercise. A trial arrangement was explored for providing one programme on a national basis to each country. It was assumed that

- (a) service areas may correspond to a transmitting-aerial beam with an elliptical cross-section of any chosen angular dimensions, subject only to the limitation that the minimum angular width should be 0.5° , and the maximum 2.0° ;
- (b) the satellite position for each service should not differ greatly from the longitude of the centre of the service area. Preference was given to a satellite position a few degrees west of the target area, and the extreme limits considered permissible were 20° west and 15° east of the target area;
- (c) the total number of frequency channels available would be four; these are not necessarily adjacent channels, but for convenience are designated channels 1, 2, 3 and 4.

4.1. Choice of service areas

As a first step elliptical areas were fitted to countries on a projection of Europe into plane; this plane was chosen at a tangent plane to the Earth at latitude 50°N and longitude 5°E , and projection was made back along lines converging on a satellite at position 5°E . The service areas derived in this way could be provided by elliptical beams from the projected satellite position, and also from other satellite positions within about $\pm 30^\circ$ with a slight distortion of the shape, which was not considered an important error in the trial study.

4.2. Protection from transmitting-aerial directivity

The next step was to calculate for each pair of service areas the protection against mutual interference provided by transmitting-aerial directivity. It was assumed that along any line from the centre of an elliptical zone the radiated power would fall off by the law given in Equation 1. This was used to determine the reduction in signal at the point where the line joining the centres of a pair of service areas, starting from one service area, meets the limit of the other service area, taken as the ellipse rather than the national boundary. (Since, with minor exceptions, the ellipse completely circumscribes the country, this tends to

err on the safe side.) Because the wanted signal at the service limit is 3 dB below the maximum, the protection was evaluated as 3 dB less than the reduction so determined. The protection was taken as 0 dB wherever service areas overlapped on the line joining their centres.

The result of these calculations are not reciprocal, i.e. service A may be better protected from service B than B is from A. This is because, assuming that the effective radiated powers at the centres of the service areas is the same, there will be greater interference from A if it is served by a wider beam than B. For planning purposes it is necessary to assume the smaller protection figure, because a pair of countries can only share the same channel if the interference is adequately suppressed both ways. (Any additional protection from receiving aerial directivity will be the same in both directions, assuming a single standard type of receiving aerial.)

The results of these calculations* can be set out in a matrix showing the lower of the two protection figures, in dB, given by the transmitting aerial of one service at the edge of another. Part of such a matrix is given in Table 3 for the first 10 countries (a to j) of the list of 39 countries examined.

TABLE 3

Matrix of transmitting-aerial contributions to protection in dB

(a)									
5	(b)								
0	7	(c)							
0	0	0	(d)						
7	5	2	0	(e)					
0	10	4	5	11	(f)				
10	14	5	9	13	8	(g)			
14	16	9	12	13	14	7	(h)		
3	11	0	1	8	4	2	11	(i)	
10	17	3	7	11	2	1	12	0	(j)

This matrix shows for example that between countries (b) and (j) a protection of at least 17 dB is obtained because of the directivity of the transmission beams that cover the assumed service areas.

4.3. Satellite positioning and receiving-aerial contribution to protection

Guided by the results of Section 3 it was arranged that satellite positions at 5° intervals of longitude should be considered available over the approximate range of longitude of the countries considered (23°W to 37°E).

* The whole of the work in fitting service areas and computing these results has been carried out by R.S. Sandell, J.H. Causebrook and R.W. Lee.

It was also envisaged that four channels would be available.

If two service areas share the same channel but are served by satellites with a longitudinal separation of ϕ , we may assume as in Section 3 that the receiving aerial will give an additional protection given by Equation 1 with ϕ_0 equal to the receiving aerial beamwidth of 2°. With a fixed set of satellite positions at equal intervals, the additional protection is a simple function of the number of units of separation.

4.4. Logical basis of assignment for computer trials

A computer programme* was arranged to take countries in turn and assign a channel and satellite position with a simple priority of choice given below, subject to satisfactory protection on the assigned channel from all services already put on that channel. This involves use of the matrix already prepared for the transmitting aerial contribution, and for each trial assignment a check is made that when the receiving aerial protection is added the total reaches the chosen figure (e.g. 30 dB) for each service already assigned on the proposed channel. If the protection ratio attains or exceeds the target value, the assignment is confirmed and the next country considered. If protection is inadequate the next priority of assignment is tried.

The order of priority for channels is numbers 1, 2, 3 and 4. The order of priority of satellite position is, relative to the longitude of the centre of the service area (rounded to 5°): stage (a) 5°W, 10°W, 15°W, 0°, 5°E; stage (b) 20°W, 10°E, 15°E. Slightly different programmes can be run, e.g. one can try all channels on the preferred satellite position before moving on to the next satellite preference, or try all satellite positions on the preferred channel 1 before moving on to the next channel preference. A compromise which was adopted is to go partly through the satellite priority, e.g. stage (a) above, before moving on to the next channel and, in the event of failure on all four channels to go through the channels again permitting stage (b) of the satellite priority.

4.5. Results of trials

Table 4(a) gives the key letters used for the 39 countries listed approximately in order of decreasing population. Two results are given in Tables 4(b) and 4(c) in which the small letter designating a country appears in the column indicating the satellite position assigned to it, and in the row corresponding to the channel assigned to it. Both results are for 30 dB co-channel protection ratio; they are among the more successful, only failing to find a solution for two or three relatively small countries. These are very preliminary results, but are of interest in showing that nearly every country (apart from the very smallest) in an area such as Europe can have one of four frequency channels assigned together with an orbital position and beam specification. This would provide one programme for each country.

* Prepared by R.W. Lee.

TABLE 4(a)

List of countries and longitude of centre

a	W. Germany	9°E	n	Hungary	19°E	a'	Finland	25°E
b	Great Britain	2°W	o	Morocco	6°W	b'	Syria	37°E
c	Italy	13°E	p	Algeria	3°E	c'	Tunisia	10°E
d	France	3°E	q	Portugal	8°W	d'	Norway	8°E
e	Spain	4°W	r	Belgium	5°E	e'	Ireland	8°W
f	Poland	20°E	s	(spare index)	—	f'	Israel	35°E
g	Turkey	35°E	t	Greece	22°E	g'	Lebanon	35°E
h	Egypt	31°E	u	Bulgaria	26°E	h'	Jordan	36°E
i	Yugoslavia	18°E	v	Sweden	16°E	i'	Albania	20°E
j	Roumania	25°E	w	Austria	14°E	j'	Libya	18°E
k	E. Germany	12°E	x	Iraq	44°E	k'	Cyprus	33°E
l	Czechoslovakia	17°E	y	Switzerland	8°E	l'	Malta	14°E
m	Netherlands	6°E	z	Denmark	9°E	m'	Luxembourg	6°E
						n'	Iceland	18°W

TABLE 4(b)

First example of trial assignments (no solution for h' or m')

Channel	West					East							
	23°	18°	13°	8°	3°	2°	7°	12°	17°	22°	27°	32°	37°
1	n'	e	—	b	o	a	j'	a'	c	x	f	—	g
2	—	e'	q	—	d	—	v	i	k'	z	h	j	b'
3	—	—	p	—	m	c'	k	t	—	l	f'	u	—
4	—	—	d'	w	—	r	l'	n	y	i'	g'	—	—

TABLE 4(c)

Second example of trial assignments (no solution for z j' or m')

Channel	West					East							
	23°	18°	13°	8°	3°	2°	7°	12°	17°	22°	27°	32°	37°
1	—	e	—	b	e'	a	—	t	f	f'	—	g	—
2	—	r	e'	—	d	—	—	c	k'	j	h	v	g'
3	—	—	o	y	l'	k	—	i	h'	m	n	x	—
4	—	q	n'	p	d'	w	—	i'	l	a'	u	b'	—

5. Discussion of results

5.1. Requirements for one national service in all countries

The approach to satellite broadcasting has so far been on the basis of providing national programmes. The idealised lattice studies of Section 3 gave an indication of the channel width and number of channels that might be employed to best advantage. Although either three or four channels were indicated, four channels were tried in the studies of Section 4 in which national boundaries were taken into account, because the higher degree of overlap of services would tend to require more channels. The main conclusion of Section 4 is that four channel capacity would be quite fully stretched to provide services to all countries, and some small countries could not be included. Moreover, some assignments of satellite position were east of the target area, which would mean that solar cells would be in shadow before about 2330 hours local time, in periods of the year near the equinoxes. It would therefore seem necessary to allow for some improvement by employing five rather than four channels of 24 MHz bandwidth, i.e. 120 MHz. Tolerance of errors in transmitting and receiving aerial alignment is another factor so far ignored which the increased bandwidth would provide for.

These conclusions are very closely parallel to those of a similar study for 'community' reception of a satellite service⁵ in which, because of the more directional receiving aerials assumed, it was concluded that 100 MHz was sufficient for a television programme to each of about 30 countries in the European area, after making allowances for tolerances.

5.2. Programme choice and alignment of receiving aerials

It is natural that the establishment of any new system of direct satellite broadcasting should provide for a choice of more than one programme. The cost and complexity of the receiving system should be kept as small as possible, and this means a fixed aerial which in any given service area would have to be permanently aligned on one particular stationary satellite position. This in turn dictates that all programmes planned for a viewer in any given place should originate either from the same satellite or from satellites in the same orbital position to an accuracy that keeps them well within the assumed 2° receiving aerial beam.

Now if all programmes were national, there would be no particular difficulty in repeating channel and satellite position assignments in the same way as in the block of frequencies of about 120 MHz providing the first programme. But it seems at first sight attractive to provide at least one service from a single satellite transmission covering a large part of Europe. If an international programme were to be provided in this way, receiving aerials throughout a large part of Europe would then be set up pointing towards a single orbital position. National services could not then be provided efficiently, because they would all have to be transmitted from the same orbital position (assuming that the undesirable re-alignment of aerials as part of the tuning

procedure is to be avoided); this loss of efficiency in terms of spectrum would arise because the receiving aerial discrimination could no longer contribute to the protection against interference, and a separate frequency channel would be needed for each national programme.

We are forced to the conclusion that, if the most efficient use of the available spectrum is of prime importance, and if a single fixed receiving aerial is to be employed, it would be necessary for such international programmes to be relayed by a series of satellites taking up the same orbital position and system of channel assignment as for the national service. Some consolation may be gained from the reduced power required for each transmission to a smaller area as compared with the higher power that would be needed for a large coverage area. It is also clear from the illustrative schemes of Table 4 that, with suitable agreements, satellites in a given position can provide not only all the services for one country but might also provide services for up to four countries. In this way saving of satellite costs might not be far short of the saving achieved by a satellite with one high-power transmission for a large area.

Nevertheless, these considerations suggest a possible compromise by co-ordinating satellite positions in a way that permits some sharing of satellite services. The main difference between the examples of Table 4(b) and 4(c) is that in the latter case some attempt was made at language grouping by amending the preferred satellite positions and also changing the order in which countries were considered. Because it was assumed that only four channels were available, the requirement for countries of similar language to have the same satellite position was achieved only to a limited extent. Thus in Table 4(c) we find that groups (i) W. Germany, E. Germany and Austria, (ii) Spain and Portugal, would be served by satellites with the same orbital position. This does not mean that programmes are fully interchangeable, but it does mean that, for example, in those parts of Austria within the W. German service area, aerials aligned for the Austrian service are also able to receive (on another channel) the German service, and vice versa. It would seem that further study is required of spectrum requirements if grouping is extended; for example neither the Scandinavian countries, nor the U.K. and Eire, were successfully provided with a common satellite position in the example of Table 4(c).

6. Conclusions

This report gives a preliminary indication of the possibilities of satellite broadcasting services in the 12 GHz band in the European area, solely from the point of view of arranging the co-existence of many national services without mutual interference. The tentative conclusion is that 120 MHz of the available band is the minimum necessary for provision of one independent programme for each country. For a choice of several programmes this figure would be multiplied by the number of programme choices.

The conclusion is based on a study which has made a number of simplifying assumptions, the most important of which are as follows:

- (i) The satellite position could be permitted to be up to 20°W or 15°E of the target area longitude.
- (ii) It would be feasible to have transmitting beams of elliptical cross-section down to a minimum dimension of 0.5° .
- (iii) Very large countries were not considered, and a maximum dimension of 2° was taken for the transmitter beams.
- (iv) A form of wideband modulation would be used, f.m. being assumed for this study.
- (v) Provisional data on co-channel interference protection ratios for f.m. television has been used. No allowance for the effect of providing one or more sound channels has been made either in the protection ratio or the channel spacing; this allowance is thought to be small for one sound channel but may be appreciable for multiple sound channels.
- (vi) The effect of adjacent-channel or image channel interference has been ignored.
- (vii) In the study very small countries were not included.

The results show that the provision of services to larger areas on an international scale by means of larger-power satellite transmitters with wider beams than those required for national services leads to difficulty if, at the same time, some national services are required. Basically this difficulty is the wasteful use of the spectrum unless receiving aerials can be tracked from one satellite position to another, which seems impractical on economic grounds. Mention was made of a compromise of 'language grouping' on which further studies are required to assess the additional bandwidth that might be needed.

It is important to bear in mind that the study did not include:

- (a) an examination of the situation if the scheme for national services were extended to embrace adjacent areas, particularly the African continent which has roughly the same range of longitude as Europe. Although the idealised lattice study showed that indefinite extension is possible without increase in the

requirements for frequency channels, a practical arrangement with service areas of different sizes might well require more frequency channels,

- (b) schemes with two alternative forms of polarisation of the transmitted signals (e.g. linear polarisations at right angles or circular polarisations of opposite sense of rotation) as a means of increasing protection between services; the exploitation of this would lead to some saving of bandwidth requirements and requires further study.

It is thought that the exploitation of different polarisations would roughly compensate for the difficulties encountered in providing services over a wider area. Further work is in progress on these problems, and the results reported here should be regarded as the absolute minimum requirements for bandwidth, assuming fairly good directivity of the transmitting and receiving aerials.

7. References

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